Feeding the World with Data: Visions of Data-Driven Farming

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ABSTRACT

Recent years have seen increased investment in data-driven farming through the use of sensors (hardware), algorithms (software), and networking technologies to guide decision making. By analyzing the discourse of 34 startup company websites, we identify four future visions promoted by data-driven farming startups: the *vigilant* farmer who controls all aspects of her farm through data; the *efficient* farmer who has optimized his farm operations to be profitable and sustainable; the *enlightened* farmer who achieves harmony with nature via data-driven insights; and the *empowered* farmer who asserts ownership of her farm's data, and uses it to benefit herself and her fellow farmers. We describe each of these visions and how startups propose to achieve them. We then consider some consequences of these visions; in particular, how they might affect power relations between the farmer and other stakeholders in agriculture—farm workers, nonhumans, and the technology providers themselves.

Author Keywords

data-driven farming; data analytics; farming; agriculture; discourse analysis

CCS Concepts

•**Human-centered computing** → *HCI theory, concepts and models;*

INTRODUCTION

> By 2050, the global population is expected to increase by almost 40% to 9.6 billion people. In order to feed this drastically increasing population, the UN Food and Agriculture Organization (FAO) predicts that the agriculture industry will need to produce 70% more food while only being able to use 5% more land. This means approximately 1 billion tons more wheat, rice and other cereals, and 200 million more tons of livestock per year, on almost the same agricultural surface area. [21]

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With this opening salvo, Ernst and Young (EY) Global makes an argument typical of news coverage and sales pitches for data-driven farming systems—software, sensors, and data analytics tools designed for use on farms. With the world's population rising and climate change disrupting ecosystems, farmers will have to feed more people with fewer resources. EY Global and others argue that the only way to solve this impending hunger crisis is to make farms more efficient, increasing productivity while cutting inputs. This will be accomplished through data-driven farming.

This argument fits into a larger narrative of technological progress in which new technologies enable ever greater efficiency and productivity in agriculture. Mechanization, chemical fertilizers, and GMOs have delivered major productivity increases in the past; data-driven farming is expected to continue this trend. Major seed, agrochemical, and equipment suppliers (DowDuPont, Bayer-Monsanto, John Deere), as well as many smaller suppliers (*e.g.,* Beck's Hybrids), have seized the opportunity to develop their own data analytics platforms. A variety of startup companies have also arisen offering data-driven farming products and services [15].

Startups signal business ideas in the process of being realized. As such, they embody discourses about the nature of farming (what farming is like today), problems in farming (what farmers need/want), and the future of farming (what farming should/will be like in the future). Ostensibly more agile and innovative than established companies, startups are poised to develop influential designs for data-driven farming. Although scholars in HCI and science and technology studies (STS) have begun studying data-driven farming and its broader impacts, especially with regard to data rights and privacy [22, 13], no work—to our knowledge—has comprehensively surveyed the landscape of data-driven farming companies to understand their visions for the future of farming.

Such a survey, we argue, can identify concretely how these platforms envision the future(s) of data-driven farming. By positioning themselves as technology and design experts, startups have the potential to reconfigure—for better or for worse—the livelihoods of farmers. Our interest in this phenomenon arose from our ethnographic fieldwork with small farmers in the U.S. [49]. In our interviews, we repeatedly encountered the perception that "technology" was only relevant for large, industrial farms: big farms are high-tech, small farms are low-tech. This made us wonder if data-driven farming was entirely a large-farm phenomenon, and what its role might be in the ideological contests between different forms of agriculture. Through a discourse analysis of startup company websites, we answer the following questions: What problem framings do data-driven farming startups use to talk about their products, and how do these framings include or exclude different types of farmers? What future visions are they promoting, and what would be the consequences if these visions are realized?

We identify four future visions depicted on the websites of data-driven farming startups: the *vigilant* farmer, the *efficient* farmer, the *enlightened* farmer, and the *empowered* farmer. We explore variations of these future visions and offer critiques. In particular, we highlight how these visions of data-driven farming can produce or exacerbate problematic power relationships between farmers and particular actors—nonhuman nature, technology providers, and farm laborers. The identification of these visions and our critiques point to the need to better understand where these visions come from, how values are (intentionally and unintentionally) integrated into the design processes of these startups, and whether data-driven farming and its visions are—in practice—beneficial to the livelihoods of farmers, farm laborers, and other stakeholders.

DEFINING DATA-DRIVEN FARMING

Data use in farming has a long, rich history. Farmers and agronomists were collecting and using data—in the form of paper records and, more recently, spreadsheets—long before the current "digital revolution." What is new today is the combination of sensors (hardware), algorithms (software), and networking technologies that has been variously referred to as "precision agriculture," "digital farming," and "Big Data in agriculture." We use the term "data-driven farming" not to suggest that farms were not previously "data-driven," but rather to draw parallels with uses of (big) data in other professional domains, such as policing [54] and medicine [47]. In general, "data-driven X" entails the use of (usually quantitative) data and computer-enabled statistical analysis to guide decision making. It builds on the premise that computers—with their ability to process large quantities of data and discern patterns that are not always noticeable to humans—can improve on merely human decision making, leading to better outcomes.

"Data-driven farming" involves data from sensors, cameras, and Internet of Things (IoT)-enabled farm equipment, as well as data that is manually entered by farmers and farm workers or imported from other online services (*e.g.*, weather forecasts). Figure 1 shows examples of data-driven farming that involve combinations of hardware, software, and/or cloud computing.

RELATED WORK

Critical Data Studies

We draw on two lines of research that critique data-driven systems: one that questions the supposed objectivity of data, and one that describes conflicts during the adoption of data-driven systems in workplaces. Environmental sensing data are often taken to be objective representations of reality, but scholars have observed that measurements construct the phenomena they purport to measure [20, 40, 43]. Moreover, differences in instruments, data gathering procedures, and systems of organization frustrate efforts at collaboration and longitudinal studies, making metadata an important resource [43, 18].

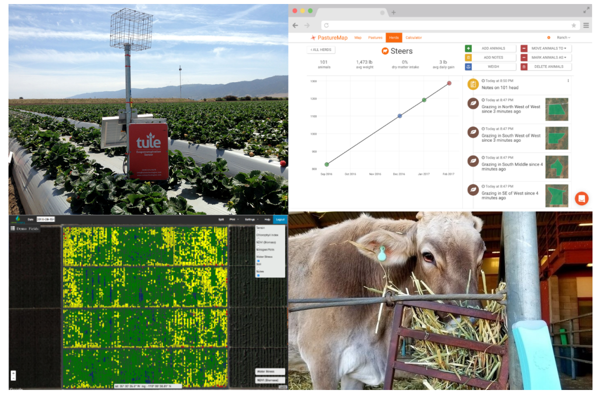

Figure 1. Top left: Tule evapotranspiration sensor deployed in a field. Top right: PastureMap herd performance dashboard. Bottom left: Image generated by Ceres Imagery, showing "water stress" in a field. Bottom right: HerdDogg smart ear tag and "DoggBone" receiver

HCI and STS scholars have studied data initiatives in various domains, such as policing [54], truck driving [29], medicine [47], and philanthropy [11]. A common criticism arising from these studies is the danger of reducing embodied, qualitative knowledge into quantitative data. This abstraction and rationalization of knowledge has led to perceived decreases in autonomy and prestige among workers. In Levy's [29] ethnographic study of truck drivers, data-driven fleet management systems allowed dispatchers to intervene in decisions that once would have been made by drivers based on their years of experience ("road knowledge") and their assessments of the situation at hand. Similarly, Sholler *et al.* [47] describe how clinical decision support systems used in hospitals "standardize and externalize [doctors'] medical knowledge, challenging years of hard-earned experience and intuition." Verma and Dombrowski [54] observed the same phenomenon when interviewing employees of a metropolitan police department that had adopted a "data-driven policing" strategy: some police officers felt that too much reliance on data weakened police *metis*, the ability to make in-the-moment judgments based on lived experience and intuition. Farmers expressed similar concerns about the uptake of precision agriculture technologies at the end of the 1990's [53], and work on farming has affirmed the "tacit, experience led, and embodied" nature of much of farmers' knowledge [44]. Together, this work shows how data systems focused on productivity and efficiency can negatively reconfigure and restrict people's practices. Next, we discuss work in HCI on agriculture and food systems as well as critical perspectives on data-driven farming systems.

HCI and Agriculture/Food Systems

Sustainable HCI has shifted from its early focus on persuasive design to a more holistic systems perspective [25, 17]. HCI researchers have unpacked the role of technology and design in creating more sustainable food systems at all points in the food chain [35, 10]. Reporting on fieldwork with local food networks, Prost *et al.* [42] propose food democracy as a theoretical framing for HCI work that engages with food systems, and they suggest six principles to guide food system change. Liu *et al.* [30] critique the "command and control" model of sustainable agriculture which focuses on policing and correcting unsustainable practices. They propose permaculture—a philosophy of sustainable farming which stresses working with rather than against nature—as an alternative model for sustainable HCI. These high-level agendas focus on creating more equitable food systems that are inclusive of non-mainstream farmers, a goal with which we sympathize.

For the most part, HCI work on food and sustainability has focused on urban issues. It has tended to emphasize problems with food access and distribution in cities, as well as urban gardening and urban farming projects [36, 37, 24], sidelining rural issues. This is a problem in HCI proper [22], but it is particularly problematic for the study of food systems, in which rural actors inevitably play key roles. A few studies have looked at the technology needs and practices of rural farms in Global North [49, 27] and Global South [28, 38] countries. However, there has been less attention paid to commercially available data-driven farming tools, many of which target rural spaces. This is a significant gap because these technologies and the discourses surrounding them are influencing the nature of farming, with implications for sustainable HCI.

Critiques of Data-Driven Farming

While HCI has not explicitly critiqued data-driven farming, a body of work has argued for studies to question the "digital revolution" taking place in agriculture [13]. Data collection and use on farms is by no means new, and precision agriculture techniques, such as yield-mapping, were already in use two decades ago [53]. But today's data-driven farming technologies distinguish themselves both from early precision agriculture systems and from lower-tech forms of record keeping by the "real-time" nature of the data, the aggregation of data from multiple farms, and the transfer of data custody from the farmer to the agricultural technology provider (ATP) [51]. The rate of data collection has intensified, and the scope of uses for the data—its "analytic potential"—has broadened [13].

Ethical concerns about data-driven farming have largely centered on privacy and ownership of farm data. Farmers worry about losing control of their data and/or having it used against them by ATPs and government. A survey by the American Farm Bureau in 2014 found that farmers feared government officials gaining access to their private information and using it for market speculation [14]. Commentators have warned that ATPs in possession of farmers' data could engage in discriminatory pricing and could shut down potential competition by withholding historical data from new ATPs, making it harder for them to develop robust predictive algorithms [51]. In response to farmers' concerns, the Global Forum on Agricultural Research, the American Farm Bureau, and others have published manifestos affirming farmers' right to control data that is gathered on their farms [41, 7]. The Farm Bureau developed a set of privacy and security "core principles" for farm data, and they award "Ag Data Transparent" certification to ATPs that meet their criteria. However, scholars have questioned whether this approach, modeled on the "notice and choice" privacy self-regulation of Internet companies, adequately protects farmers' interests [51]. Carbonell [14] alternatively proposes open-data initiatives and publicly-funded analytics platforms to weaken the power of ATPs.

Other work has raised concerns about the effects of data-driven systems on farmers' practice. Thus far, data-driven farming technologies have been designed for, and primarily used by, "monoculture industrial farms." [14] The marketing of these technologies arguably shows a bias in favor of "farming that can be 'rationally managed' as technology-maximizing, profit-oriented businesses" and against less technological forms of farming, which are painted as "parochial, folksy and backward" [13]. With regard to the ethical implications of data-driven farming, Bos et al. [12] suggest that data-driven systems could mitigate the objectification of animals in industrial farming because they embody values of care; but at the same time, such systems redefine care in quantitative and instrumental terms and so risk sidelining the qualitative experience of the animals and farmer. Mateescu and Elish [33] affirm the need to consider context when implementing new farming technologies; in particular, they spotlight the "human infrastructure" that is necessary to integrate data-driven systems into existing farming practice. These ongoing conversations provide context for our analysis of data-driven farming discourse. In turn, our study grounds these critical conversations in a systematic analysis of the future visions promoted by data-driven farming startups.

METHODS

In order to conduct a discourse analysis of data-driven farming technologies, we sought but could not find a freely available list of agriculture technology startups. Aggregators such as Crunchbase [2] and CB Insights [6] maintain such lists, but access is restricted to paid subscribers, and their methodology for collecting data is opaque. Similarly, venture capital platform AgFunder [1] claims to have a proprietary database of 11,000 agrifood technology companies. Their data reportedly comes from Crunchbase as well as their own "private communications with investors and companies." However, they have not published this data, and they declined to share the list of startups with us when asked (via email).

AgFunder's 2017 investment report [15], however, does provide a useful framework for classifying agrifood tech companies, which we used to guide our data collection. AgFunder identifies and defines eight categories of "upstream" agrifood tech: Ag Biotechnology; Farm Management Software, Sensing and IoT; Farm Robotics, Mechanization and Equipment; Bioenergy and Biomaterials; Novel Farming Systems; Supply Chain Technologies; Agribusiness Marketplaces; and Innovative Food. Our definition of data-driven farming aligns with AgFunder's second category, Farm Management Software, Sensing and IoT, defined as "Ag data capturing devices, decision support software, [and] big data analytics."

We created our own list of Farm Management Software, Sensing and IoT startups by first identifying (through Google searches) accelerators and incubators that focus on agrifood tech. Most such programs list their "portfolio" companies or "alumni" on their website; companies on these lists that fell into the Farm Management Software, Sensing and IoT category were added to our own list. We also found companies through online news articles (*e.g.*, [48]); through a search of the software review platform Capterra [5]; through F6S [3], a platform that connects startups with prospective investors and employees; and through the site AgTech Guide [4]. Our list contains 129 active companies founded after 2000, of which 75 are U.S. based. Although we do not claim to have identified *all* Farm Management Software, Sensing and IoT startups, we believe our list is relatively complete and representative for the U.S. as of fall 2018.

For analysis, we selected companies that:

- were founded in the previous five years (2013-2018)
- have an office in the U.S. and/or explicitly target U.S. customers (as the U.S. is the site of our ongoing fieldwork and the cultural context with which we are most familiar)
- have a functioning website (ruling out defunct companies as well as some very new companies that do not yet have a product or user base)
- target farmers as their user base (as opposed to, *e.g.*, agricultural consultants or feedlot managers)

We also strove for broad representation across product types and target demographics. Our final sample consisted of 34 companies, including one (Digital Harvest) founded before 2013 and two (Agribotix and Granular) that had recently been acquired by larger companies but maintained their own websites. After 34, we had largely exhausted the available data (that is, companies meeting our criteria that had a significant online presence) and had reached analytic saturation. For each company, we downloaded every non-blog page on the company's website. (For websites that included a large number of blog posts, we collected a sample of the blog pages.) Additionally, we downloaded all video and audio files present on the website. In some cases, we downloaded news articles linked to by the website, or searched Google for news articles and videos about the company if these were not linked from the website. The non-blog web pages (in most cases, a home page, About Us, Contact, FAQ, and product description page(s)) and accompanying images and videos formed the bulk of our data. We supplemented this with blog posts and news articles when the website data was sparse, but we did not comprehensively analyze these additional sources.

We applied emergent discourse analysis [39] to the data. Discourse analysis unpacks not only what texts (*e.g.*, the websites in our dataset) say but how such texts are rendered meaningful through tactics such as dissemination and rhetorical strategies. We analyzed each company individually, then compared our company-level analyses to identify recurring themes and tropes. Underlying our analysis is a commitment to considering the present-day problems of farming, the imagined data-driven farming of companies, and the possible mismatches between the current and imagined. This focus on future visions, conversely, says much about the present—"how problems of today are perceived, framed, and understood [9]." Our analytic approach is thus informed by approaches like those of Su *et al.* [50] and Harmon and Bopp [23].

TEXT CORPUS

The companies in our study can be roughly classified into seven categories according to the type of product or service they provide. For simplicity, we have placed each company into only one group, although, in reality, there is some overlap between categories.

- **sensors and analytics (18 companies):** rent or sell stationary (for crops) or wearable (for animals) sensors to automate data collection and an analytics platform to interpret and visualize data
- **farm management software (7 companies):** provide a platform to collect, interpret, and visualize data; generally do not provide their own hardware; rely on data that is manually entered by farmers or imported from other services
- **aerial imagery and analytics (3 companies):** rent or sell camera-equipped drones to farmers or (more often) collect aerial images using their own fleet of drones or planes; supply an analytics platform to interpret and visualize data
- **robotics and analytics (2 companies):** provide robots to automate or partially automate (*e.g.*, via remote operation of robots) aspects of farm labor; often accompanied by an analytics platform
- **data sharing networks (2 companies):** provide farmers with a platform to sell or freely share data about their farm, and access data from other farms
- **food tracing (1 company):** provides scannable labels for hand-harvested produce, supplying logistical information for farmers and food chain transparency for consumers
- **mobile voice interaction service (1 company):** converts voice recordings into structured data, streamlining in-the-field note-taking

FINDINGS

Through our analysis of data-driven farming startups' discourse, we identified four future visions of farming: the *vigilant* farmer (control), the *efficient* farmer (optimization), the *enlightened* farmer (harmony with nature), and the *empowered* farmer (data ownership). Two of these—control and optimization—were nearly omnipresent in the discourse. These visions are foundational to data-driven agriculture and are embraced by almost all the companies in our study. In this section, we describe all four visions and the features of data-driven farming tools that will (supposedly) help bring them about.

Control: the vigilant farmer

Farming is an uncertain occupation in which output depends on many factors outside of the farmer's influence. This is particularly problematic in our current global food system, in which farm products are treated as commodities, with buyers expecting consistent quantity and quality from their suppliers. Accordingly, data-driven farming companies appeal to farmers' desire for greater control—the ability to produce consistent, predictable yields month over month and year over year with minimal risk. Data-driven farming tools promise to provide greater control through comprehensive, accurate

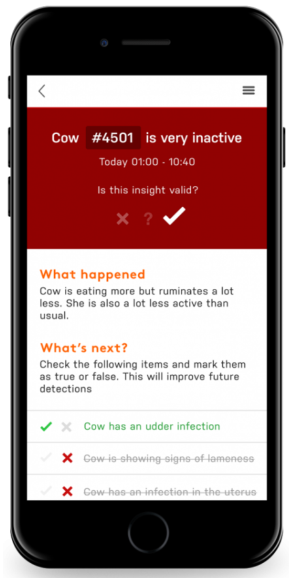

Figure 2. An alert prompting the farmer to check on a possibly ill cow (Promotional image from wearable maker Connecterra)

data, delivered in "real time," rendered in the form of usable "insights," accessible at any time, anywhere through a single dashboard. These insights (the companies claim) will help farmers achieve control by averting surprises, ensuring data integrity, and reducing uncertainty in decision-making.

Eliminating surprises with algorithms

Data-driven farming startups portray a future in which technologies keep farmers constantly informed about conditions on their farm and alert them to potential problems immediately so they can take quick action to mitigate losses. For example, Cowlar, a maker of wearables for cows, boasts, "Our complex algorithms take nearly every possible thing into account to make sure you do not miss a single health issue with your farm." In addition to notifying farmers of problems, digital alerts also make sure farmers never miss an opportunity. Cowlar's website promises that "the farm [will be] notified immediately via text, email, on our dashboard or phone call from our customer success agent" when a dairy cow enters estrus (*i.e.*, when she is able to become pregnant and should be inseminated). According to Cowlar and other companies, this quick detection of both problems and opportunities is beyond the abilities of human workers. Whereas humans have limited time and attention—they cannot observe a cow 24 hours a day or inspect every plant in a field—technological monitoring is continuous and comprehensive. Moreover, the companies suggest, their sensing technologies can detect anomalies more reliably than humans. Consequently, farmers need data-driven farming technology to catch everything that might fall through the cracks of human attention.

Data integrity with the Cloud

Companies emphasize the immediacy and durability of their data, which is stored in "the Cloud" and can be accessed or updated from farmers' mobile devices. In doing so, they represent older technologies as inconvenient, unreliable, ineffective, or inefficient. For instance, a customer of farm management software company PastureMap is quoted as saying, "Before PastureMap, grazing records and monitoring were just scraps of paper and emails flying between the teams." In this farmer testimonial, the paper and email records are ephemeral, easily lost or destroyed, and hard to locate when you need them. By contrast, the digital records kept by PastureMap are durable, stable, centralized, and easy to access. The quote implies that the integrity of the data stored on paper and in emails is questionable. By comparison, the integrity of PastureMap's records, standardized and safely stored in the Cloud, seems more certain. Companies often talk about the Cloud as if it is a physical place—a pocket dimension where data is simultaneously always-accessible and private. The CEO of food-tracing company Food-Origins says his company "send[s data] from the field to the cloud," and when someone accesses that data by scanning a product label, they "go to the cloud" to get it. The Cloud is an abstraction that hides the materiality and discontinuity of data storage, providing a comforting vision of stability and security.

Eliminating uncertainty with quantification

Data-driven farming companies promise to "take the guesswork out of farming," delivering certainty through quantification. Many of these companies make the claim that measuring something—quantifying it—is a necessary and sufficient condition for improving it (usually defined as improving efficiency). Associated with this belief is a strong preference for quantitative over qualitative data. In promoting their soil moisture monitoring system, crop analytics provider FarmQA says, "Knowing how much water your crops need is sometimes more art than science. Now there's a better way." Science is clearly preferred; the implication is that art (deciding how much to water based on the farmer's intuition, born of experience) is messy, while science (measuring to determine "exactly" how much water the plants need) is precise. They urge farmers, "Don't guess how much nitrogen you have in your soil, know." Similarly, a farmer in a promotional video for precision irrigation company WaterBit says, "Always before, I used experience and historical knowledge to really *guess*, through trial and error.... WaterBit allows me to have those metrics to *know exactly*." The phrasing of this quote suggests, counterintuitively, that decisions informed by "experience," "historical knowledge," and "trial and error" are no better than blind guesses; "metrics"—numbers—are the gold standard for accuracy. Another quote in the same video anticipates that data-driven farming tools will negate farmers' experience entirely: "We can learn more in the next two seasons of applying this technology... than we've learned in the past three thousand years." The implications of this statement are staggering: IoT and data analytics are so superior to all other ways of knowing that within two years, they will make three millennia of accumulated agricultural knowledge obsolete. By measuring and quantifying the farm, data-driven farming tools supposedly turbocharge knowledge production. This, in turn, reduces farmers' risk of making bad (uninformed) decisions.

Optimization: the efficient farmer

Almost all data-driven farming companies promise to optimize farm operations by helping them manage their time and resources more efficiently. Optimization is presented as the key to improved quality of life for farmers (through time management), improved sustainability (through resource management), and lower labor costs (through automation of farm work). Ultimately, optimization serves to decrease spending, increase yields, and make farm businesses financially secure.

Liberating farmers through time management

According to the company websites we analyzed, efficient time management is achieved by (1) prioritizing tasks, (2) automating routine tasks, and (3) eliminating churn caused by poor organization and communication. The payoff for this increased efficiency is that farmers can have more freedom in how they spend their time. Some companies promise to relieve farmers of boring clerical tasks so they can get to tasks which are a better use of their time, energy, and abilities. Granular (a maker of farm management software for large farms, now owned by agricultural chemical company DowDuPont) is one of these companies: they appeal to farmers who want to be "in the field," away from the drudgery of "manual data entry in the office" doing more important things like "making key business decisions and spending time with family." AgCinect (farm management software) similarly observes that "the average farmer is more interested in planting than paperwork," and Farmbrite (farm management software designed for the needs of small farmers) promises to get "out of your way so you can focus on your farm." Conversely, other companies stress the ability to do more work from home or an office instead of driving or trudging across a large farm, or simply to "relax" away from the farm. In this vein, WaterBit says, "With our automated irrigation solution, growers don't even have to leave their kitchen table to get precise irrigation to their crops—they can do it using their mobile phone or computer." This contrast signals that the companies are walking a fine line when it comes to automation. On the one hand, they want to play up automation's time-saving potential. On the other, they do not want farmers to feel that their way of life is being threatened or that their labor and expertise are not valued. Different companies come down on different sides of this line. But all promise to liberate farmers from tedious work, giving them more time to do what is important to them.

Resource management for sustainability and profit

Sustainability and profitability are traditionally seen as incompatible; being environmentally sustainable is harder and costs more, and is only worthwhile for a business if they can attract conscientious and affluent customers willing to pay a premium for sustainable products [16]. Some data-driven farming companies start from the assumption that farmers would like to adopt more sustainable farming practices but do not feel it is financially viable. The companies challenge this received wisdom, saying that their products can make sustainability profitable for farmers. For instance, PastureMap states that their "mission is to help farmers and ranchers make profits building healthy grasslands." The word "profits" reinforces the idea that PastureMap brings financial benefits to farmers. "Building healthy grasslands" evokes sustainability. Together, they say that profit and sustainability are not mutually exclusive but, in fact, go hand in hand—when farmers use PastureMap's software. Sustainable practices (in the case of PastureMap, regenerative grazing) "increases revenue and lowers feed costs." PastureMap "makes it easier to adopt regenerative grazing practices that heal the land" and make money for farmers. Sustainability is the main objective, and profit is a means to achieve it—or, alternatively, a "reward" for farmers who do right by the environment.

Other companies stress that for farm businesses to survive and meet global demand for food in the face of resource scarcity and climate change, they must become more efficient, which includes using natural resources judiciously. For these companies, as for PastureMap, sustainability and profit go together. But instead of increased profits enabling farmers to be sustainable, being sustainable (in terms of resource management) is represented as a means to increase profits. Granular claims that sustainability and efficiency are synonymous, or at least that efficiency is a precondition for sustainability: "Sustainable farms capture the essential factor of business efficiency and align it with a long-term outlook. The scale of operations, the number of workers, the extent of mechanization. . . do not matter." They seem particularly interested in promoting the idea that sustainability is not limited to boutique or small farms—big farms can be sustainable, too (and in fact may be *more* sustainable): "Sustainable farming is not 'sound science' or 'organic' or a term meant to be applied to certain small farms." In contrast to PastureMap's somewhat romantic narrative—in which farmers and ranchers ("the heroes and heroines of our story") are engaged in a noble quest to "heal the land" through sustainable farming—Granular's pragmatic and flexible definition of sustainability is likely to appeal to large, profit-minded farms.

Automating and streamlining labor

Companies do not suggest that farming should or will be entirely automated. They are careful to specify that automation will not replace the farmer/operator. For instance, Cowlar tries to downplay potential threats to farmers' autonomy from their sensing device: "Since it's practically a harmless collar and not a robot, it cannot physically perform any actions but rather tells you to perform them, just at the right time." This keeps farmers in control (like a driver-assisted self-driving car). However, some companies play up the potential for automation to replace farm *workers*: "Cowlar reduces your need of labour & the headache of manageing [*sic*] them." The assumption is that human workers—who have needs and agendas of their own, and must be trained, managed, and compensated—are inefficient by nature; automation is more time- and cost-effective. As an alternative to full automation, Digital Harvest, a robotics and analytics company catering to very large farms, proposes to solve labor shortages by "virtually connect[ing] workers and the farm." In an interview, the CEO envisions a future in which fruit pickers remotely operate robotic arms from hundreds or thousand of miles away: "Theoretically the 'work crew' could be in an air-conditioned room anywhere in the world, operating virtual pruning shears that instruct real pruning shears in a California vineyard." This system represents the ultimate in efficiency: it eliminates the need to bring workers (often seasonal laborers from Mexico) to the physical farm, effectively allowing large farms to outsource their labor needs.

Another alternative to complete automation of farm labor is to use data-driven farming tools to manage employees. The terminology startups use to discuss workforce management reflects a variety of relationships between farmers and their employees. Some, like PastureMap, use language that would not sound out of place in a white-collar office, for instance, "Stay on the same page as your team." Quotes like this stress the need for better communication and collaboration, and suggest a relatively egalitarian work organization. By contrast, the CEO of Food-Origins emphasizes his technology's potential use as a performance management tool: "As employees become more valuable, we could maximize that resource, giving them the capacity to be the most productive, and rewarding those who are the most productive." These "rewards" consist (in the short term) of higher pay for more productive workers. Eventually, the CEO says, Food-Origins' customers can quantify workers' contribution in order to make optimal decisions about hiring and wages: "In the long term, we're going to be able to spell out how much [employees'] work is worth." In this vision, employees are one more "resource" that farmers will manage efficiently via data.

Harmony with nature: the enlightened farmer

The enlightened farmer uses data to better understand and work in harmony with nature (the natural world personified). The premise of this vision is that there is something wrong with the current relationship between farmers and nature—that farmers are in conflict with or simply disconnected from nature. Agrotics (a company that provides analytics based on soil sensors and weather data) represents the farmer-nature relationship as a "battle" where Mother Nature has "the upper hand" thanks to unpredictable weather. But once a farmer adopts Agrotics' product, they can "work in harmony with mother nature [*sic*]." Most other companies represent nature, not as hostile to farmers, but as misunderstood and potentially mistreated by farmers due to an inability to communicate. Data-driven farming tools promise to bring farmers into harmony with nature by augmenting farmers' ability to understand nature and by enabling nature to "talk to" farmers.

Revealing nature's hidden workings

Companies who promote this vision promise that their products will help farmers understand nature using a combination of sensors (to pick up on information too subtle for humans to sense) and data analytics (to uncover hidden patterns in plant and animal behavior). Connecterra (a maker of wearables for cows) says, "We imagine a future where livestock, land, water, even the atmosphere, are all connected by tools that help humans make sense of the biosphere's hidden internal language." The data that sensing devices collect will help farmers to be more in tune with the "health" and "emotions" of plants and animals. For instance, HerdDogg (which also makes wearables for cows) promises to turn farmers into empathic animal whisperers by alerting them to subtle changes in cows' physical and emotional states. By consulting HerdDogg's app on their mobile phones, farmers will be able to answer previously un-answerable questions like, "Is the animal happy?" Having this window into the secret inner life of nature, companies claim, will allow farmers to care for their animals and crops more effectively.

Giving nature a voice

Some companies advertise that their products will give agency and a voice to nature, facilitating communication between humans and the natural world. For instance, HerdDogg, says, "Your herd should be able to send you insights without any stress or injury to you or them." This statement represents cows as frustrated communicators who want to talk to farmers but don't have a good way to do so. HerdDogg alternately represent their product as a passive data collection system and a vehicle for cows to express themselves. In 2017, they demoed their product at the National Western Stock Show by putting the wearables on Longhorns and posting data the devices collected to Twitter. The CEO said in an interview, "The animals themselves are really tweeting." It is not just animals who can "talk" through technology, as crop analytics company Teralytic promises: "With this kind of [sensor] network, a farm can 'talk' to a computer." This is a different spin on the same functionality we discussed in the previous section, which allows farmers to peer into the mysteries of nature. This representation hides the algorithmic work of generating insights from data by implying that the algorithms are simply translating what nature has to say.

Data ownership: the empowered farmer

There are two main orientations toward farm data ownership, reflected in the data metaphors that companies use. On one hand, data is often described as a *byproduct* of farms' activities—something they already produce, knowingly or not, the way Internet users are said to leave digital traces that can be used by marketers and researchers—or a *crop* that can be deliberately cultivated, harvested, and sold for profit. Both of these metaphors conceptualize data as something independent of technology companies. On the other hand, some companies represent data as a farming *input* which—like seeds, chemicals, or equipment—is produced and dispensed by a company. Hence, the term "data provider" used by Aker (crop scouting via drones), and Arable's (crop analytics) description of their mission: "We feed data to those who feed the world." In this view, data is something the company sells to the farmer to improve their farming operation. It is primarily a product of sensors and software. Some companies actively push back against this second interpretation, urging farmers to assert ownership over the data produced on their farms. The empowered farmer not only controls and profits from their own data, they share that data with their peers for mutual benefit.

Democratizing data

Large agribusinesses control much of the inputs and equipment that big farms need. Farmers have clashed with them over Right to Repair [8] and being forced annually to buy GMO seeds [34]. Now these same companies are also trying to control farm data by launching their own analytics platforms and/or buying startups like the Climate Corporation and Granular. They want data to flow through their systems and be interpreted by their agents, making themselves gatekeepers. Some data-driven farming startups oppose these efforts by agribusiness, promising to "democratize" farm data. The website of Farmers Business Network (FBN), a data aggregator, positions the company solidly in opposition to agribusiness, with repeated assertions that FBN is "independent and unbiased" and will "level the playing field for independent farmers." FBN and similar companies aim to keep data in the hands of farmers, in this case a collective of farmers who are members of their "network." Farmers can access this (anonymized) shared data by paying and/or sharing their own data. This type of "democratic" data sharing is analogous to an equipment co-op in which farmers who can't afford to buy expensive equipment can pay to access a shared pool of equipment. Farmobile, the other data-sharing company in our sample, also style themselves as an "independent farm data company" and a champion of farmers' data rights, although the service they provide is less a collective data pool than a data marketplace where farmers can "turn data into dollars" on their terms. Democratization of farm data, then, means empowering individual farmers and preventing data monopolies—not necessarily making farm data accessible to all.

The power of networks
The assumption underlying all these data aggregation efforts is that more data leads to more and better insights; the "bigger" the data, in terms of the "five V's"—volume, variety, velocity, veracity, and value [32]—the better the results. In terms of a single farm, companies claim it is better to collect more types of data, at more time points, from more sources. But some companies go farther to suggest that data from any one farm is valuable only in combination with data from other farms. The website of FBN, explaining the reasoning of the farmers who founded the company, says, "Working together, they knew they could learn vastly more than by looking only at just their own farms, thereby unlocking the true power of the precision farm data they'd paid for." They imply that seeing the big picture requires context from outside the farm, so a farmer looking at only their own data is essentially wearing blinders. The potential of farm data is unlocked only when combined with data from other farms. There is a suggestion that data providers (other than FBN) are handicapping farmers by forcing them to focus narrowly on their own farms, thereby denying them the collective power that comes from being fully informed. Accordingly, some data-driven farming companies create data sharing networks to maximize the benefits of data analytics. Granular claims that their network allows farmers to share knowledge quickly and easily, without the need for in-person meetings: "Granular customers don't have to wait for a winter meeting to learn from peers or travel somewhere else—they can do it every day from their office by comparing anonymized metrics collected in the software." In this vision of empowerment, data sharing networks fulfill the promise of the Internet by putting data about hundreds of geographically distributed farms at each farmer's fingertips.

DISCUSSION: ENTANGLED VISIONS
In this discussion, we critique the aforementioned future visions. Rather than question the plausibility of these visions, we focus on the consequences for farming should these futures come to pass. Because these future visions are necessarily entangled—that is, one often accompanies another—we cannot see benefits and risks of technological solutions in terms of one single vision. Instead, we consider the balance of power between farmers and other agricultural stakeholders, and how data-driven farming startups might impact these power relations. Along with critique, we suggest alternative paths that data-driven farming designers could take. Our critique is meant to highlight conflicts both within data-driven farming discourses and recent discussions in HCI focused on sustainability and alternative farming.

The Farmer and Nature
The need for farmers to be vigilant and efficient stems partly from nature's mercurial character. Unexpected weather events or health problems have significant costs [49]. Data-driven farming promises to combat this unpredictability through algorithms, giving farmers greater control and security. At the same time, startups invoke visions of the enlightened farmer in harmony with nature. To what extent does harmony with nature entail control over nature, and when is this kind of harmony desirable?

Care and de-centering humans in farming
To better understand startups' visions of harmony with nature, it is useful to compare and contrast them with a different idea of farmer-nature harmony from the HCI literature—Liu *et al.*'s [30] concept of symbiotic encounters between human and nonhuman actors within farm ecosystems. They propose a model of environmental sustainability that de-centers humans, positioning farmers not as conquerors of the natural world, but as part of it. Instead of farmers controlling nature, Liu *et al.* observed relationships between farmers and nonhuman actors that were characterized by intimacy, emotional connection, and care, in which farmers attempted to work with, rather than exploit, nature (*i.e.,* permaculture).

In some cases, the visions of data-driven startups do appear to de-center humans by giving nonhumans "agency," but this is usually in service of the farmer's goal of control. HerdDogg's wearables enable cows to "talk" so that they can tell farmers about "issues," such as health problems, that need to be addressed. The communication is structured, purposeful, and one-way: farmers receive data about animals which prompts them to act. It is hard to say that the cows in this example truly have agency when they have no say over what data is collected about them, when, or how it is used. Tellingly, we found no mention in startups' discourse of personality or individual differences among animals—no stories spotlighting a farmer's relationship with a particular nonhuman. The goal of decoding "the biosphere's hidden internal language" is less about communication than it is about demystifying (and thereby rationalizing and standardizing) farming. Our findings support Bos *et al.*'s [12] assertion that data-driven livestock farming glosses over qualitative differences between animals and encourages farmers to see animals as means to an end.

There is a case to be made that data-driven farming systems support caring relationships between farmers and nonhumans by implementing values such as "attentiveness, responsibility, competence and responsiveness" [12]. The vigilant, technology-enabled farmer who is aware of their farm and acts decisively to solve problems is arguably a better caretaker than they would be without the technology. This is almost certainly true for large farms where farmers cannot know all parts of the farm intimately. In other contexts, where data-driven farming tools potentially create distance between farmers and nature by automating previously hands-on tasks, they may hinder the intimate understandings that Liu *et al*. advocate.

Environmental sustainability

With respect to the role of new technologies in sustainable farming, Liu *et al*. defer to the everyday innovation of farmers. HCI's focus, they argue, should be on enabling broad participation in technological innovation among farmers. Liu *et al*.'s suggestion to democratize innovation by creating toolkits for farmers echoes Carbonell's [14] solution to farm data ownership and privacy worries: open-sourced data and publicly funded analytics platforms. Both of these suggestions reflect a belief that sustainable, equitable food systems will be created from the bottom up, not from the top down. They attempt to check the consolidation of power by preventing private actors, such as technology companies, from hoarding data or claiming a monopoly on technical expertise and invention. This scholarly perspective, with its sympathy for alternative forms of farming, seems incompatible with the vision of optimization that defines sustainability in terms of efficiency.

When they equate sustainability with efficiency, agricultural technology providers (ATPs) narrow the field of possible solutions. They mandate a quantitative, metric-focused approach to sustainability. This type of approach is best suited to large farms who can take advantage of economies of scale; hence, this definition of sustainability serves to justify and preserve the power of Big Ag. Carbonell [14] similarly observes that "big data analytics seems to solve and thereby sanction the problems of big agriculture: if the modern large-scale farms and businesses are not sustainable given their externalities, big data analytics... will come to the rescue and allow them to lower the environmental cost of farm inputs." In other words, by focusing on the problems of large-scale agriculture, analytics providers foreclose more radical solutions to sustainability, which might require reconfiguring the food system.

The Farmer and Technology Provider

As profit-driven companies, startups seek to create a place for themselves in the food system as producers, interpreters, aggregators, and/or brokers of farm data. We should consider what their relationship to farmers will be and how power manifests in this relationship. Scholars have addressed this question with respect to data ownership, asking, for instance, who ought to own the data and insights produced by data-driven farming tools [51, 14], whether farmers are being fairly compensated for the use of data that they own [41], and whether the data that companies possess gives them unfair financial advantages over farmers [51, 14]. These are important questions, but here we want to raise questions about subtler power dynamics implicated in startups' tangled visions of the future.

Data vs. metis

Data-driven farming provides a bounty of real-time data to the now *vigilant, efficient, empowered*, and *enlightened* farmers who make decisions with confidence and certainty. In defining certainty as a result of algorithmic insights gleaned from quantitative data, data-driven farming leaves no room for farmer *metis*—the intuitive knowledge that comes from embodied experience [45]. Devaluing metis threatens farmers' identity and autonomy, and it shifts power to ATPs as the source of authoritative (scientific) knowledge. The former effect has been observed in various data-driven workplaces [47, 54, 29]. While visions of vigilant, efficient farmers enlightened and emboldened by data are compelling, we can imagine an alternative (equally extreme) framing that venerates farmers as craftspeople who possess metis, gained through experience, which allows them to make farming decisions based on keen qualitative observations.

Efforts to replace metis with scientific knowledge in the name of efficiency and productivity are not new. They date back to Taylor's [52] system of "scientific management," which aimed to externalize craftspeople's knowledge about how to do their work, converting it into a set of rules which could be easily taught and followed. Data-driven farming systems seeking to optimize farm work are doing the same; they shift decision-making from the domain of the farmer to the domain of the technology provider. For Taylor, the mechanism by which embodied knowledge would be converted into rules was the scientific method. By conducting thorough and meticulous experiments, engineers would determine the optimal organization of work for each job. In today's data-driven workplaces, including farms, experimentation is now being replaced with the more nebulous and opaque mechanism of data analytics. ATPs take in data and, via proprietary algorithms, produce "insights" for farmers to act on. To the extent that this process excludes farmers, it increases the relative power and prestige of technology companies and their knowledge.

Networks and #FarmerPower

Many of the companies in our study propose to give farmers either direct or indirect access to aggregated data from other farms. Some, like Farmers Business Network, claim that they are empowering farmers relative to ATPs by enabling farmers to share data with each other. Other companies, such as Granular, more modestly claim that their data sharing networks will make farms more efficient by eliminating the need for farmers to meet in person to share knowledge. Yet, data-sharing networks are *not* a replacement for the social networks formed through interactions. Unlike an in-person meeting, data-sharing networks are not spaces for farmers to talk and share advice. They are pools of anonymized data, provided by farmers but maintained by and accessed through technology companies. Although their stated goal is to bring farmers together and help them realize their collective power, they could be said to separate farmers by replacing face-to-face meetings and communities with faceless metrics. Whether this truly empowers farmers, increases the power of ATPs relative to farmers, or simply shifts power to different ATPs (the data-sharing platforms) remains to be seen.

Black-boxed systems

The data-driven farming companies in our study frequently tout the technology novice-friendly nature of their systems. They present farmers with all-in-one systems, packaged for ease of use and requiring minimal input or maintenance from the farmer. This strategy has a downside, however: by making closed/black-boxed systems, companies make it harder for farmers to customize their tools, and, thus, limit the systems' potential. Small farmers habitually create ad hoc solutions to problems they encounter [49], appropriating technologies as they see fit [26]. Accordingly, data-driven farming systems should be designed to facilitate farmers innovating and building on them. Software design is a process with no endpoint; systems must be continuously (re)designed to accommodate changing requirements. Thus, making systems that are open instead of closed, allowing farmers to understand how they work and modify them if desired, could make such systems less brittle and increase their longevity (an important factor in farming, where expensive pieces of equipment remain in use long after the high-tech world has declared them obsolete.) If data-driven farming systems are black-boxed, it will be harder for farmers to adapt these systems to their farms' changing needs. Farmers will depend on companies to listen to their feedback and produce timely system upgrades.

The Farmer and Farm Workers

Historically, new technologies have often disrupted farm labor [55]. Data-driven farming systems expose farm workers to the double risk of automation and increasingly intrusive surveillance practices. Visions of replacing human workers with well-behaved machines are not new, and they have a long history in U.S. agriculture [31]. This future abstracts farm work away from its material context: workers become, not individuals with unique knowledge and skills acquired from experience, but faceless, interchangeable laborers. The most extreme example of this abstraction in our data is Digital Harvest's vision of a future in which laborers operate harvester robots from air-conditioned buildings miles away, never setting foot on the farm or meeting the farmer face-to-face. Tellingly, this is exactly the future depicted in the dystopian science fiction film *Sleep Dealer* (2008), which was likely created in response to visions like Digital Harvest's [31].

Data ownership and privacy in data-driven farming promise to create an empowered farmer who uses their farm's data to maximum effect. The Ag Data Transparent core principles [7] state, "We believe farmers own information generated on their farming operations." They add the caveat that "it is the responsibility of the farmer to agree upon data use and sharing with the other stakeholders with an economic interest, such as the tenant, landowner, cooperative, owner of the precision agriculture system hardware, and/or ATP etc."

One group is notably absent from this list of stakeholders: farm workers. Yet, data-driven farming systems, by design, collect data from workers. This includes data that workers themselves create when they use the system to communicate with farmers or other employees, or to document their work tasks. It also includes data that is captured about them. The *efficient* farmer's use of this data—primarily to evaluate workers and adjust their pay accordingly—is potentially problematic. But equally troubling, and less talked-about, is the risk to workers from having this data shared beyond the farm. At best, this is a breach of workers' privacy; at worst, it can endanger already vulnerable workers who are undocumented or came to the U.S. on farm work visas.

We do not know how these technologies will impact workers' practices and their relationships with their (farmer) employers, but they are likely to exacerbate inequalities between employers and workers, given how data-driven farming discourse devalues workers' labor. Additional work is necessary to understand how such systems could be designed to be inclusive of workers' concerns.

Future Work

In this paper, we have characterized data-driven farming and the futures that new data-driven startups are trying to enact. Additional work will help to determine how these entangled future visions play out in practice, and how they interact with the visions of farmers and other stakeholders. Research into the design processes of these companies and their interactions with farmers may concretely identify places where farmers' values clash with those of technology designers. The sources of tension may be different for different types of farms and farmers; small or alternative farmers and large-scale, industrial farmers likely have different (though overlapping) value sets (*e.g.*, they may identify more or less strongly with an efficient and vigilant farmer). Our sense is that data-driven farming as a whole is still closely aligned with industrial farming, although there are hints that some startups are sympathetic to alternative forms of farming. This may reflect the rise of the "New American Farmer" [19], young people who are new to farming and have motivations (like disenchantment with urban life) that differ from conventional farmers, suggesting a rejection of the Taylorism inherent in the visions we identified.

As our findings show, a great deal of innovation in data-driven farming is happening outside the purview of academic HCI. While HCI scholars can study these technologies and their impacts and suggest design directions, they must convince companies to accept their ideas—not trivial in an industry where entrepreneurs are encouraged to "move fast and break things"—in order to influence development [46]. Designer-researchers can combat this mindset by embedding themselves within companies, where they can influence the design process formally or informally as "value advocates" [46]. We suggest that value sensitive design strategies of influencing from within, applied to agriculture, can promote inclusive futures for data-driven farming technologies.

CONCLUSION

Data-driven farming startups promise a future in which data helps all farmers preside over smooth-running, efficient, and sustainable farm businesses. In a critical analysis of these startups' discourses, we have identified and problematized four future visions presented by data-driven farming startups. Naïve acceptance of these visions benefits entrenched interests and is not likely to produce meaningful change. But by taking a critical perspective on data-driven farming technologies, designers can guide their development in a way that both benefits farmers and helps to achieve HCI's desired outcome of sustainable and equitable food systems.

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